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A review on the pattern of electricity generation and emission in Iran from 1967 to 2008☆

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ABSTRACT

The electricity consumption growth in Iran requires a rapid development of power plant construction. Like many other countries, most of the power plants in Iran are using fossil fuel. In the past decade, thermal power plants generated about 94% of electricity and about 6% was generated by renewable sources such as hydro-power. This study is to show a clear view of 42 years an evolutionary trend of Iran's electricity generation industry. The capacity of power generation installed and electricity generation from the years 1967 to 2008 has been gathered. The total pollutant emissions and emission per unit electricity generation for each type of power plants have also been calculated using emission factors and the pattern of electricity generation and emission has been presented. The results shown that encouraging of using renewable energy sources and increasing the contribution of the combined cycle as a best type of thermal power plants and use more natural gas is recommended to reduce emission.

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☆ The statistical data and information given in this study correspond to the Iranian year beginning on March 21. Therefore, the year 2008 refers to a 1-year period from March 21, 2008 to March 20, 2009.

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1. Introduction

1.1. Energy supplies of Iran

Iran has an area of 1,648,195 km^2, with a population of about 70 million based on the latest census in 2006, 48 million of which live in the urban area and 22 million live in the rural area [1]. The country is a member of OPEC (Organization of Petroleum Exporting Countries) that controls about 78% of the world oil reserves and produces about 45% of the world oil production. Iran is one of the major exporters of energy such as crude oil and natural gas with approximately 11% of world oil reserves (136 billion barrels). It has the second largest reserves of natural gas in the world with approximately 19.7% of the world proven natural gas reserves which are about 28,080 billion cubic meter [2].

1.2. Electricity generation in Iran

The power industry in Iran, including power generation, transmission and distribution facilities, is owned, operated and administrated by the Ministry of Energy (MOE) through its executive organizations which include TAVANIR (Power Generation and Transmission Management Organization) and the regional power companies.

In 2006 with over 45 GW installed nominal capacity, Iran ranks 17th in the world and 1st among the middle east countries [3]. In 2008, electricity generation in the country reached to 214 TWh, it growth of about 5.0% in comparison to previous year.

Nomenclature

CV	calorific value (kcal/m^3)
EF	emission factor in power plant (kg/Mm^3)
EG	electricity generation from power plant (GWh)
EM	power plant emission (ton)
EP	emission per unit electricity generation (kg/GWh)
EX	exchange electricity with neighboring countries (GWh)
FC	power plant fuel consumption (Mm^3)
FE	share of fuel emission (%)
k, *C*	constant values
NC	power plant nominal capacity (MW)
NP	share of nominal capacity (%)
P	population
PC	per capita electricity consumption (kWh)
PE	share of electricity generation (%)
PF	share of thermal energy (%)
PN	per capita nominal capacity (W)

Subscripts

f	fuel type consumed in power plant
i	in the year *i*

Superscripts

n	power plant type
p	emission type
t	thermal power plants

1.3. Non-renewable power plants

At present, most of Iranian power plants are using non-renewable sources such as natural gas, fuel oil and diesel to generate electricity. These power plants are steam turbine, combined cycle, gas turbine and diesel engine. Detailed information about electricity generation and fuel consumption used by these power plants is discussed in Section 2.

1.4. Steam turbine power plants

Steam turbine power plants produce the steam at the high purity, high pressure and high temperature for the steam turbine to drives the electrical generator. Currently steam power plants have 15,598 MW nominal capacity equivalents to 29.5% of total nominal capacities and produce 45.4% of total electricity generation in the country. The efficiency of these power plants in Iran is about 36% [4].

1.5. Combined cycle power plants

This type of fossil fuel power plant uses the gas turbine in conjunction with a heat recovery steam generator (HRSG). It is referred to as a combined cycle power plant because it combines the Brayton cycle of the gas turbine with the Rankine cycle of the HRSG. This type of power plants has 11,117 MW nominal capacity equivalents to 21.0% of total nominal capacities and produce 26.6% of total electricity generated in the country in 2008. The thermal efficiency of these plants in Iran is about 44% [4]. The maximum efficiency of combined cycle plants has reached a record heat rate of 5690 Btu/kWh, or just under 60%, at a facility in Baglan Bay, Wales [5].

1.6. Gas turbine power plants

Gas turbine power plants without steam cycle are sometimes installed as emergency or at peak load or in places which difficult to find water recourses to use for steam power generation; their thermal efficiency is about 29% which is much lower than combined cycle power plants [4]. Today, gas turbine power plants in Iran have 18,077 MW nominal capacity equivalents to 34.1% of total capacities and produce 25.6% of total electricity generated in the country.

1.7. Diesel engine power plants

The purpose of diesel engine power plants was as backup power plants for hospitals, water pumps and industries that needed to ensure a reliable power supply at all times. Today diesel engine

power plants represent some 10–15% of the total installed capacity all over the world but only under 0.1% in Iran [6]. The efficiency of this type of power plants in Iran is about 32% [4].

1.8. Renewable power plants

Renewable energy is generated from renewable resources such as wind, solar, hydro and geothermal. Non-hydro renewable energy comprises about 5% of global power generating capacity and supplies about 3.4% of global electricity production [7].

The ecological and geographical characteristics of Iran is well suited to a diverse and extensive use of renewable energy sources. In addition, demographic diversity large population in scattered and remote areas with different climates dictates to use all sources of renewable energy in Iran for better and equitable access to energy [8]. At this time, Iran is using renewable resources such as hydro and wind to generate electricity. Detailed information of renewable power plants nominal capacity and electricity generation is presented in Section 2.

1.9. Hydro-power plants

Hydro-power is more expensive initial cost but provides continues supply of electricity with the high efficiency and longer life span of infrastructure. Its considerably reduces energy losses, enhances network stability and provides the higher availability factor comparing to the other types of power plants if water resources is available well.

Table 1
Fuel types consumption in all types of Iranian thermal power plants.

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Natural gas	x	x	x	–
Diesel	x	x	x	x
Fuel oil	x	–	–	–

x = fuel is consume in power plant, and (–) = fuel is not consume in power plant.

The average annual rainfall of Iran is about 250 mm, compared to the world (with an average annual rainfall of 750 mm) Iran is considered as one of the dry countries. Therefore, it is natural that Iran was unable to use all its hydro-power capacities. For example, in 2008, only 2.2% of electricity have been generated using hydro-power plants, although these plants have 14.5% of total nominal capacities.

1.10. Wind turbines

Iran has a large wind potential due to its geographical location [9]. This is a scientifically reliable for the regions offshore and onshore. This potential could offer many advantages of wind power generation and supplying to national distributing network including job creation in the country.

Table 2
Nominal capacity (MW) for various types of Iranian power plant from 1967 to 2008.

Year	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Hydro-power	Wind energy	Total
1967	343	84	–	198	309	0	934
1968	351	98	–	250	309	0	1,008
1969	437	128	–	286	462	0	1,313
1970	434	135	–	310	517	0	1,396
1971	746	135	–	316	800	0	1,997
1972	746	172	–	372	804	0	2,094
1973	1,359	241	–	390	804	0	2,794
1974	1,587	410	–	414	804	0	3,215
1975	1,576	610	–	459	804	0	3,449
1976	1,722	658	–	505	804	0	3,689
1977	1,719	1,507	–	541	1804	0	5,571
1978	1,719	2,887	–	614	1804	0	7,024
1979	2,476	2,936	–	705	1804	0	7,921
1980	3,983	3,058	–	783	1804	0	9,628
1981	4,423	3,175	–	830	1804	0	10,232
1982	4,423	3,201	–	880	1804	0	10,308
1983	5,045	3,150	–	923	1804	0	10,922
1984	5,445	3,271	–	899	1804	0	11,419
1985	6,285	3,309	–	971	1804	0	12,369
1986	6,855	3,438	–	891	1827	0	13,011
1987	7,155	3,492	–	837	1827	0	13,311
1988	7,475	3,489	–	803	1914	0	13,681
1989	8,086	3,600	–	803	1953	0	14,442
1990	8,086	3,940	–	824	1953	0	14,803
1991	8,086	3,940	–	869	1953	0	14,848
1992	8,710	4,794	–	856	1953	0	16,313
1993	9,513	5,934	–	812	1953	0	18,212
1994	10,742	6,960	–	758	1953	0	20,413
1995	11,557	7,746	–	658	1953	0	21,914
1996	11,621	8,168	–	662	1969	0	22,420
1997	11,685	8,896	–	677	1999	0	23,257
1998	12,400	9,422	–	616	1999	0	24,437
1999	13,102	9,530	–	574	1999	0	25,205
2000	14,126	6,770	3,760	533	1999	0	27,188
2001	14,776	7,565	4,060	533	1999	11	28,944
2002	14,840	6,857	6,290	490	3028	12	31,518
2003	14,904	7,663	6,832	493	4420	16	34,328
2004	15,229	9,710	6,832	493	5012	25	37,301
2005	15,577	12,050	6,832	493	6043	37	41,032
2006	15,553	14,862	7,836	418	6572	47	45,288
2007	15,598	15,433	10,479	418	7422	63	49,413
2008	15,598	18,077	11,117	418	7672	63	52,945

In recent years, Iran has made considerable progress in utilizing wind energy. Until the end of 2008, 113 wind turbines was installed in several regions of the country with total capacity of 63 MW.

1.11. Other energies

There is much other energy related projects in Iran. The country currently launching and developing new energy sources such as nuclear and various renewable sources like solar thermal, solar photovoltaic, geothermal, biomass, bio-gas, hydrogen, wave and fuel cells, which are all under feasibility study or still under development [10].

1.12. Power plants fuel consumption

The type of fuel use for power plant in a country depends on many factors, especially economic, politic and technical parameters. These parameters include cost of the fuels, geographical location of the power plants, availability of the fuel, environmental concerns and medium and long-term policies of the energy sector. Fossil fuels such as fuel oil, diesel and natural gas are the main fuels use in Iranian thermal power plants. However, mostly the power plants use natural gas as a primary-fuel, except for diesel engines and the power plants that are far from national gas pipelines.

There are also emergency backup fuels for power plants. For example, in the winter when the residential usage of natural gas maximized, due to pressure drop in the national gas pipeline, some power plants switch their fuel type. Superseded fuel for steam power plants is fuel oil and for gas turbine and combined cycle power plants is diesel oil. Diesel oil is unique fuel for diesel engines and only used at the starting stage for steam power plants. The types of fuel consumed in Iranian power plants are presented in Table 1.

1.13. Energy policy in Iran

In recent years, several actions have been taken in order to increase the efficiency and capacity of power generation such as empowering gas turbine for some plants, removing the limits on some generation units and equipping the gas turbines of combined cycle power plants with cooling systems for inlet air [11]. The installation of steam turbine units next to gas turbines in order to combined cycle have been done in many power plants. This resulted in higher efficiency of the unit, and less consumption of fuels subsequently lower emission released.

1.14. Power plants emission

In general, thermal power plants operated by fossil fuels produce huge amounts of air pollutants. The pollutants which have been considered in this study are carbon monoxide (CO), sulfur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen oxides (NO_x).

Like other developing countries, the majority of energy sources used in Iranian power plants are fossil fuels [12]. Nevertheless, the fuel consumption profile in Iran is significantly different from other

Table 3
Electricity generation (GWh) for various types of power plant from 1967 to 2008.

Year	Steam turbine	Gas turbine	Combine cycle	Diesel engine	Hydro-power	Wind energy	Total
1967	732	56	–	396	658	0	1,842
1968	1,088	77	–	411	855	0	2,431
1969	1,336	85	–	440	1,336	0	3,197
1970	1,978	155	–	452	1,671	0	4,256
1971	2,097	194	–	520	2,679	0	5,490
1972	2,513	265	–	564	3,528	0	6,870
1973	5,374	541	–	567	2,842	0	9,324
1974	6,545	688	–	511	3,421	0	11,165
1975	7,785	955	–	593	3,445	0	12,778
1976	8,455	1,122	–	659	3,975	0	14,211
1977	8,203	2,558	–	781	4,213	0	15,755
1978	6,316	3,928	–	893	6,249	0	17,386
1979	7,769	5,327	–	926	5,419	0	19,441
1980	8,197	5,088	–	976	5,620	0	19,881
1981	9,174	5,883	–	1120	6,229	0	22,406
1982	12,562	6,141	–	1173	6,447	0	26,323
1983	16,296	6,826	–	1184	6,203	0	30,509
1984	18,309	8,780	–	1255	5,750	0	34,094
1985	20,200	9,570	–	1400	5,550	0	36,720
1986	22,860	7,160	–	1508	7,517	0	39,045
1987	25,360	7,305	–	1499	8,390	0	42,554
1988	26,968	8,146	–	1350	7,311	0	43,775
1989	33,056	6,974	–	1173	7,522	0	48,725
1990	38,836	8,723	–	1254	6,083	0	54,896
1991	41,947	9,463	–	1244	7,056	0	59,710
1992	42,362	10,866	–	1224	9,530	0	63,982
1993	48,166	12,419	–	927	9,823	0	71,335
1994	53,376	15,402	–	863	7,445	0	77,086
1995	55,901	16,145	–	723	7,275	0	80,044
1996	62,364	15,475	–	610	7,376	0	85,825
1997	65,628	19,298	–	476	6,908	0	92,310
1998	63,988	26,486	–	373	7,015	0	97,862
1999	70,689	31,156	–	419	4,943	0	107,207
2000	80,710	20,865	12,855	361	3,650	0	118,441
2001	83,510	20,344	17,899	328	5,057	31	127,169
2002	84,260	17,531	27,586	356	8,050	31	137,815
2003	87,670	17,697	32,895	290	11,094	30	149,676
2004	90,716	24,979	36,250	252	10,627	47	162,871
2005	93,383	32,129	36,194	212	16,085	69	178,072
2006	92,481	41,235	40,343	220	18,169	86	192,534
2007	94,228	37,604	53,796	225	17,987	141	203,981
2008	97,201	54,911	57,015	204	4,753	196	214,280

Table 4
Exchange electricity between Iran and neighboring countries (GWh).

Year	Export	Import	Exchange
1993	195	0	195
1994	197	0	197
1995	157	0	157
1996	384	0	384
1997	522	0	522
1998	622	144	478
1999	1125	340	785
2000	1003	326	677
2001	1049	745	304
2002	799	977	−178
2003	919	1489	−570
2004	1837	2170	−333
2005	2760	2084	676
2006	2774	2541	233
2007	2520	1842	678
2008	3875	1648	2227

Minus sign indicates more imports than exports.

developing countries. For example, the fuel type used in thermal power plants in India or China are mainly coal [13,14]. This difference plays a significant role in defining the air pollutants characteristics of power plants.

To estimation the total emission due to electricity generation in the country, the amount and type of fuel used in all power plants should be considered. Awareness the amount of emission per unit electricity generation in each type of thermal power plants is necessary for selection the best of plant type with regard to air pollutant and assess possible emission in the future.

2. Survey data

The data used for this study are based on the electricity generation, exchanged electricity with neighboring countries, fossil fuel used and population of Iran from 1967 to 2008. These data collected from Refs. [1,15,16] and shown in Tables 2–8.

The emission factors for all types of fuel with different combustion types were mostly obtained from Refs. [17,18] and given in Table 9.

The characteristics of fuels used in power plants are important to assess the contribution of each fuel in emission. The fuel oil and diesel produced by the local refineries are high sulfur content about 2.5–3.5% by weight [19] and 500–10,000 ppm [20]. Calorific values are essential to calculate thermal energy available for types of fuel. Fuel oil calorific value is 9790 kcal/l, diesel calorific value is 9232 kcal/l and natural gas calorific value is between 8509 and 9099 kcal/m^3 [16].

Table 5
Population of Iran for selected years between 1956 and 2008.

Year	Population
1956	18,954,703
1966	25,788,722
1976	33,708,744
1986	49,445,010
1991	55,837,163
1996	60,055,488
1997	61,070,425
1998	62,102,514
1999	63,152,047
2000	64,219,318
2001	65,301,307
2002	66,300,418
2003	67,314,813
2004	68,344,729
2005	69,390,404
2006	70,495,782
2007	71,532,063
2008	72,583,587

Table 6
Total fossil fuel consumption (Mm^3) for power plants from 1967 to 1978.

Year	Diesel	Fuel oil	Natural gas
1967	0.136	0.311	13
1968	0.118	0.420	33
1969	0.128	0.496	21
1970	0.165	0.672	22
1971	0.166	0.597	163
1972	0.192	0.514	346
1973	0.317	0.899	723
1974	0.399	0.846	944
1975	0.405	1.283	1077
1976	0.500	1.454	1116
1977	0.990	1.145	1533
1978	1.472	1.015	1380

3. Methodology

3.1. Method of data estimation

Some data are already available but others have to be estimated. There are several methods for estimating data; the one that widely used is polynomial curve fitting. This method tries to describe the relationship between a variable X as the function of available data and a response Y that seeks to find a smooth curve for the best fit of the data. Mathematically, a polynomial of order k in X can be expressed in the following equation form [21]:

$$Y = C_0 + C_1X + C_2X^2 + \cdots + C_kX^k \quad (1)$$

3.2. Electricity generation statistics

3.2.1. Per capita nominal capacity

The per capita nominal capacity for each year is the total nominal capacities divided by the population in that particular year. The per capita nominal capacity in the year i can be calculated by the following equation:

$$PN_i = \frac{NC_i}{P_i} \quad (2)$$

3.2.2. Per capita electricity consumption

The per capita electricity consumption in the year i is electricity production minus electricity exchange with neighboring countries, divided by population in particular year, which can be calculated by the following equation:

$$PC_i = \frac{EG_i - EX_i}{P_i} \quad (3)$$

3.2.3. Percentage of electricity generation and nominal capacity

To understand the changes in pattern of electricity generation and nominal capacity, the share of each type of power plants should be identified by the following equations:

$$PE_i^n = \frac{EG_i^n}{EG_i} \times 100 \quad (4)$$

$$NP_i^n = \frac{NC_i^n}{NC_i} \times 100 \quad (5)$$

3.3. Emissions

The methodology used to evaluate emission in power plants is the one that recommended by the Emissions Inventory Improve-

Table 7
Composition of fuel consumption (Mm^3) in power plants from 1979 to 1997.

Year	Fuel type	Steam turbine	Gas turbine and combined cycle	Diesel engine	Total
1979	Natural gas	1130.317	1204.927	–	2335.244
	Diesel	0.027496	1097.484	0.273404	1.398384
	Fuel oil	1.059709	–	0.004026	1.063735
1980	Natural gas	774.617	1503.085	–	2277.702
	Diesel	0.029057	0.662529	0.290990	0.982576
	Fuel oil	1.473125	–	–	1.473125
1981	Natural gas	609.809	1749.809	–	2359.618
	Diesel	0.012342	0.606074	0.329524	0.94794
	Fuel oil	1.90088	–	–	1.90088
1982	Natural gas	1314.114	1862.415	–	3176.529
	Diesel	0.014178	0.654858	0.341069	1.010105
	Fuel oil	1.947086	–	–	1.947086
1983	Natural gas	1748.144	1872.787	–	3620.931
	Diesel	0.037138	0.885.82	0.357342	1.2803
	Fuel oil	2.618036	–	–	2.618036
1984	Natural gas	1671.896	2212.911	–	3884.807
	Diesel	0.027312	1.221740	0.373353	1.622405
	Fuel oil	3.18322	–	–	3.18322
1985	Natural gas	1740.029	2252.319	–	3992.348
	Diesel	0.032078	1.754105	0.405650	2.191833
	Fuel oil	3.56824	–	–	3.56824
1986	Natural gas	1939.477	1916.380	–	3855.857
	Diesel	0.057668	1.152434	0.431340	1.641442
	Fuel oil	4.150225	–	–	4.150225
1987	Natural gas	3183.488	2267.896	–	5451.384
	Diesel	0.090979	0.952462	0.436766	1.480207
	Fuel oil	3.558858	–	–	3.558858
1988	Natural gas	3270.727	2459.477	–	5730.204
	Diesel	0.086041	1.041537	0.389491	1.517069
	Fuel oil	3.838877	–	–	3.838877
1989	Natural gas	4666.044	2197.405	–	6863.449
	Diesel	0.06068	0.855109	0.343534	1.259323
	Fuel oil	4.100641	–	–	4.100641
1990	Natural gas	5454.388	2861.936	–	8316.324
	Diesel	0.03391	0.750953	0.358353	1.143216
	Fuel oil	4.809136	–	–	4.809136
1991	Natural gas	5869.654	3229.731	–	9099.385
	Diesel	0.022854	0.584895	0.356913	0.964662
	Fuel oil	5.144249	–	–	5.144249
1992	Natural gas	6283.176	3574.852	–	9858.028
	Diesel	0.028592	0.717291	0.357012	1.102895
	Fuel oil	4.852909	–	–	4.852909
1993	Natural gas	6947.629	4552.992	–	11,500.621
	Diesel	0.021904	0.782294	0.26825	1.072448
	Fuel oil	5.786264	–	–	5.786264
1994	Natural gas	7767.256	4773.518	–	12,540.774
	Diesel	0.030499	0.867113	0.253085	1.150697
	Fuel oil	5.887458	–	–	5.887458
1995	Natural gas	7862.248	4730.451	–	12,592.699
	Diesel	0.044655	1.093426	0.21111	1.349191
	Fuel oil	6.700139	–	–	6.700139
1996	Natural gas	8639.874	4802.914	–	13,442.788
	Diesel	0.0322	0.800919	0.180469	1.013588
	Fuel oil	7.445886	–	–	7.445886
1997	Natural gas	9894.116	5709.612	–	15,603.728
	Diesel	0.036164	0.983047	0.141256	1.160467
	Fuel oil	7.037559	–	–	7.037559

ment Program of the US EPA (Environmental Protection Agency) [22]. These are based on emission factors for each fuel type and applied to the following four types of power plants: steam turbine, combined cycle, gas turbine and diesel engine.

As mentioned in Table 1, all power plants (except diesel engines) use more than one type of fossil fuels. This means, the emission factor of a fuel will be different based on the power plant type. For example, emission factor for diesel oil will be different

Table 8
Composition of fuel consumption (Mm^3) in power plants from 1998 to 2008.

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
1998	Natural gas	11,685.18	2572.523	5145.046	–	19,403
	Diesel	0.055484	0.418415	0.209208	0.112791	0.796
	Fuel oil	4.870239	–	–	–	4.870
1999	Natural gas	12,310.537	2338.338	6584.766	–	21,234
	Diesel	0.027701	0.662025	0.245597	0.137303	1.073
	Fuel oil	5.945605	–	–	–	5.946
2000	Natural gas	13,640.279	2816.571	6426.105	–	22,883
	Diesel	0.048485	0.72655	0.400251	0.10748	1.283
	Fuel oil	6.491761	–	–	–	6.492
2001	Natural gas	15,058.6	6342.3	3600.2	–	25,001
	Diesel	0.0079	1.1224	0.3659	0.0996	1.667
	Fuel oil	6.7988	–	–	–	6.799
2002	Natural gas	15,929.8	5409.7	6258.5	–	27,598
	Diesel	0.00741	1.1382	0.3315	0.1086	1.652
	Fuel oil	6.2753	–	–	–	6.275
2003	Natural gas	17,893	5532	6843	–	30,268
	Diesel	0.00437	0.948	0.361	0.085.9	1.439
	Fuel oil	4.938	–	–	–	4.938
2004	Natural gas	18,127	7372	7183	–	32,682
	Diesel	0.0047	1.456	0.608	0.078	2.189
	Fuel oil	5.736	–	–	–	5.736
2005	Natural gas	18,343	9506	7204	–	35,053
	Diesel	0.0064	1.862	0.660	0.062	2.648
	Fuel oil	6.329	–	–	–	6.329
2006	Natural gas	16,539	10,968	7732	–	35,239
	Diesel	0.0090	3.344	1.203	0.065	4.702
	Fuel oil	7.587	–	–	–	7.587
2007	Natural gas	16,164	10,435	10,377	–	36,976
	Diesel	0.132	2.271	2.088	0.066	4.557
	Fuel oil	8.435	–	–	–	8.435
2008	Natural gas	16,792	15,262	11,357	–	43,411
	Diesel	0.07	2.97	1.299	0.059	4.398
	Fuel oil	8.911	–	–	–	8.911

from steam turbine, gas turbine and diesel engine power plants. Because of this fuel has three different combustion type and boiler configuration in these three types of power plants.

Amount of SO_2 is directly related to the amount of sulfurs. As mentioned in Section 2, calorific value of natural gas and amount of sulfur in diesel and fuel oil has not been fixed so the mean value is used in the calculations. Accordingly, natural gas calorific value considered 8800 kcal/m^3 and the sulfur content for diesel assumed to be 5000 ppm (equivalent to 0.5%) and 3% for fuel oil.

3.4. Emission production

Emission production is equal to emission factor multiply by the amount of fuel consumed. Therefore, the emission p due to use fuel f in power plant type n in the year i, can be calculated by the following equation:

$$EM_{if}^{np} = EF_{f}^{pn} \times FC_{if}^{n} \tag{6}$$

To assess the impact of each type of fuel in total emission of each power plant, contribution of each fuel in total emission should be calculated by the following equation:

$$FE_{if}^{np} = \frac{EM_{if}^{np}}{\sum_{f} EM_{if}^{np}} \times 100 \tag{7}$$

The annual emission is the summation of emission for all types of power plants due to all types of fuel used. This can be calculated by the following equation:

$$EM_{i}^{p} = \sum_{n}\sum_{f} EM_{if}^{np} \tag{8}$$

Thermal energy released due to inflammation of each type of fuel depends on fuel's calorific values. The share of each type of fuel in total thermal energy consumed in power plants can be

Table 9
Emission factors (kg/m^3) used for estimating emissions in power plants.

Fuel type	Combustion type	Boiler configuration	CO_2	NO_x	SO_2	CO
Fuel oil	External	Normal	3040	5.63	$18.81 \times S\%$	0.6
Diesel	External	Normal	2660	5.63	$18.81 \times S\%$	0.6
	Internal	Engine	2660	72.37	$18.81 \times S\%$	0.6
		Turbine	2610	14.66	$18.81 \times S\%$	0.6
Natural gas	External	Normal	1.92×10^{-3}	4.48614×10^{-3}	9.61×10^{-6}	1.344×10^{-9}
	Internal	Turbine	1.92×10^{-3}	5.12702×10^{-3}	9.61×10^{-6}	1.344×10^{-9}

$S\%$ indicates percentage of sulfur in the respective fuel, by weight.

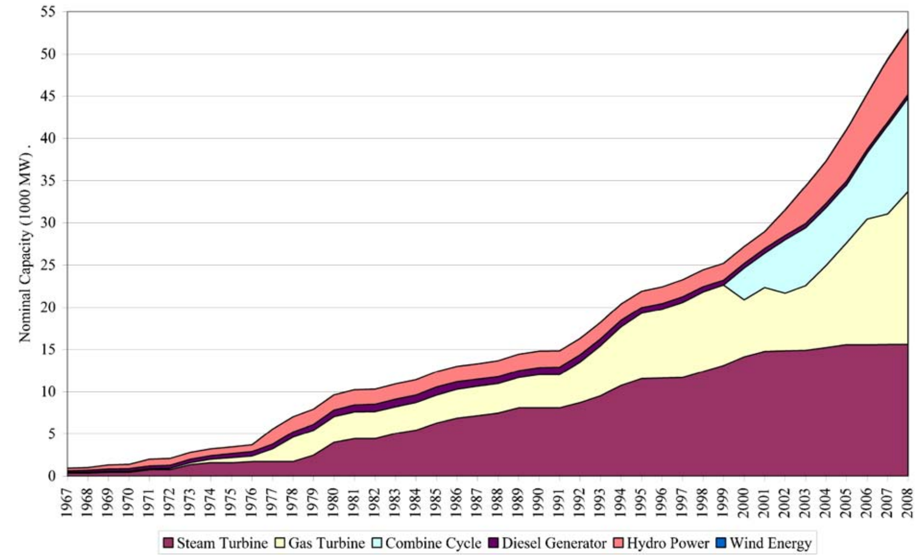


Fig. 1. Nominal capacity (MW) of Iranian power plants by type of power plant from 1967 to 2008.

calculated by the following equation:

$$PF_{if}^{n} = \frac{CV_f \times FC_{if}^{n}}{\sum_f CV_f \times FC_{if}^{n}} \times 100 \tag{9}$$

3.5. Emission per unit electricity generation

The emission per unit electricity generation for each year is a function of annual emission divided by total electricity generated by power plants. This can be calculated by the following equation:

$$EP_i^p = \frac{EM_i^p}{EG_i^t} \tag{10}$$

3.6. Emission per unit electricity generation for each type of power plant

The emission per unit electricity generation for each type of power plant is a function of the emission factor, fuel consumption in each type of power plant and electricity generation from that particular power plant. The emission p per unit electricity generation in power plant type n in the year i, can be calculated by the following equation:

$$EP_i^{np} = \frac{\sum_f EF_f^{np} \times FC_{if}^{n}}{EG_i^n} \tag{11}$$

To estimate each type of emission due to a unit electricity production in each type of power plants, only the values related to certain years are applied. The average emission for certain years considered as a selected value, calculated by the following equation:

$$EP^{np} = \frac{EP_{2000^p}^{n} + EP_{2001^p}^{n} + \cdots + EP_{2008^p}^{n}}{9} \tag{12}$$

4. Results and discussions

4.1. Electricity growth

The nominal capacity and electricity production growth by type of power plant in Iran is shown in Figs. 1 and 2.

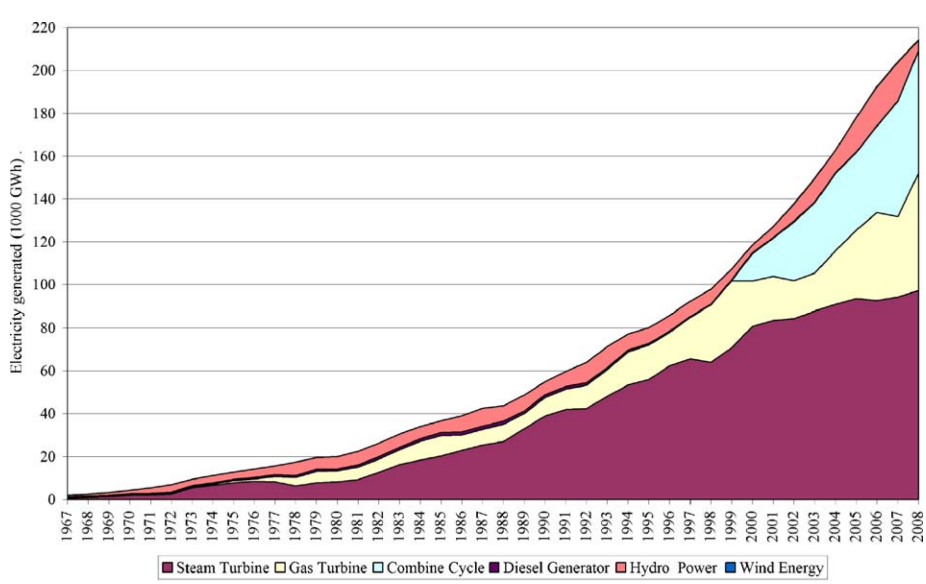


Fig. 2. Electricity generation (GWh) in Iranian power plants by type of power plant from 1967 to 2008.

Table 10
Per capita nominal capacity and per capita electricity consumption in Iran.

Year	Per capita nominal capacity (W)	Per capita electricity consumption (kWh)
1967	36	71
1968	39	93
1969	49	120
1970	51	156
1971	71	196
1972	72	237
1973	93	311
1974	103	358
1975	106	394
1976	109	421
1977	158	448
1978	192	474
1979	207	509
1980	242	500
1981	247	542
1982	240	613
1983	245	685
1984	247	738
1985	259	769
1986	264	792
1987	262	838
1988	262	839
1989	270	910
1990	270	1001
1991	265	1066
1992	286	1121
1993	314	1226
1994	347	1307
1995	368	1343
1996	373	1423
1997	381	1503
1998	393	1568
1999	399	1685
2000	423	1834
2001	443	1943
2002	475	2081
2003	510	2232
2004	546	2388
2005	591	2556
2006	642	2728
2007	691	2842
2008	729	2952

Annual electricity production growth in the country was 12.3% and annual nominal capacity growth was 10.35%. This is equivalent to annual growth of 5058 MWh of electricity production that need to create 1239 MW of new power generation capacity annually.

4.2. Per capita capacities

There is empirical evidence of a long-run relationship between per capita electricity generation and real per capita GDP in Iran [23]. The annual population growth estimated using the data in Table 5 and Eq. (1). The nominal capacity and electricity consumption per person have been calculated using Eqs. (2) and (3) based on the data in Tables 2–4. The share of exchange electricity with neighboring countries is very small (~1%), therefore, the per capita rate of electricity generation and consumption should remain the same. The results are tabulated in Table 10 and illustrated in Fig. 3.

For 42 years, from 1967 to 2008, the average of population growth in Iran was 2.5%. Nonetheless, per capita electricity consumption has increased by about 4000% equivalent to average annual growth rate of 9.5%. Electricity consumption per person increased from 71 kWh in 1967 to 2952 kWh in 2008. This very high growth is due to economic growth that caused the rate of electricity production was much higher than population growth.

4.3. Pattern of electricity generation

The pattern of electricity generation and nominal capacity, based on the power plant type is calculated based on the data in Tables 2 and 3 and equations (4) and (5). The results tabulated in Tables 11 and 12, and illustrated in Figs. 4 and 5.

Fig. 4 shows that the electricity generation from fossil fuel is much higher than renewable resources. This is due to the tendency to use more fossil fuel power plants in order to meet high electricity demand. This is also due to the huge fossil fuel resources in the country, deficiency of water resources and lack of investment in renewable sources. There are some changes in the pattern of thermal power plants. Since 2001, many gas turbines and combined cycle power plants were developed; therefore, the contribution of electricity production by this power plant has been increased. This is due to government's policy to increased contribution of gas turbine and combined cycle plants. While

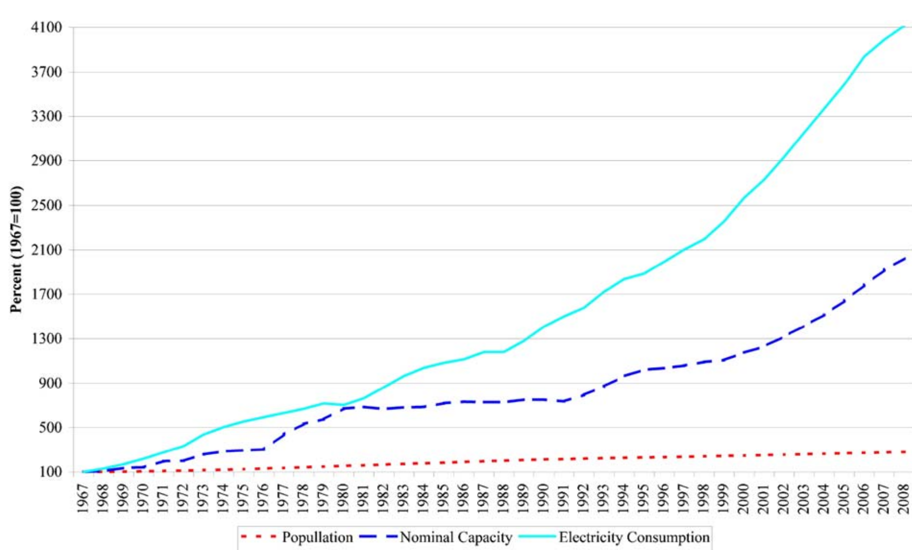


Fig. 3. Per capita nominal capacity and per capita electricity consumption and population growth between 1967 and 2008.

Table 11
Power plants electricity generation contribution (%) from 1967 to 2008.

Year	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Hydro-power	Wind energy
1967	39.7	3.0	–	21.5	35.7	0
1968	44.8	3.2	–	16.9	35.2	0
1969	41.8	2.7	–	13.8	41.8	0
1970	46.5	3.6	–	10.6	39.3	0
1971	38.2	3.5	–	9.5	48.8	0
1972	36.6	3.9	–	8.2	51.4	0
1973	57.6	5.8	–	6.1	30.5	0
1974	58.6	6.2	–	4.6	30.6	0
1975	60.9	7.5	–	4.6	27.0	0
1976	59.5	7.9	–	4.6	28.0	0
1977	52.1	16.2	–	5.0	26.7	0
1978	36.3	22.6	–	5.1	35.9	0
1979	40.0	27.4	–	4.8	27.9	0
1980	41.2	25.6	–	4.9	28.3	0
1981	40.9	26.3	–	5.0	27.8	0
1982	47.7	23.3	–	4.5	24.5	0
1983	53.4	22.4	–	3.9	20.3	0
1984	53.7	25.8	–	3.7	16.9	0
1985	55.0	26.1	–	3.8	15.1	0
1986	58.5	18.3	–	3.9	19.3	0
1987	59.6	17.2	–	3.5	19.7	0
1988	61.6	18.6	–	3.1	16.7	0
1989	67.8	14.3	–	2.4	15.4	0
1990	70.7	15.9	–	2.3	11.1	0
1991	70.3	15.8	–	2.1	11.8	0
1992	66.2	17.0	–	1.9	14.9	0
1993	67.5	17.4	–	1.3	13.8	0
1994	69.2	20.0	–	1.1	9.7	0
1995	69.8	20.2	–	0.9	9.1	0
1996	72.7	18.0	–	0.7	8.6	0
1997	71.1	20.9	–	0.5	7.5	0
1998	65.4	27.1	–	0.4	7.2	0
1999	65.9	29.1	–	0.4	4.6	0
2000	68.1	17.6	10.9	0.3	3.1	0
2001	65.7	16.0	14.1	0.3	4.0	0
2002	61.1	12.7	20.0	0.3	5.8	0
2003	58.6	11.8	22.0	0.2	7.4	0
2004	55.7	15.3	22.3	0.2	6.5	0
2005	52.4	18.0	20.3	0.1	9.0	0
2006	48.0	21.4	21.0	0.1	9.4	0
2007	46.2	18.4	26.4	0.1	8.8	0.1
2008	45.4	25.6	26.6	0.1	2.2	0.1

the diesel engine power plants were being slowly phased out in Iran. The share of nominal capacity or electricity generation of this type of power plant has been decreased from 21% in 1967 to 0.1% in 2008 because the fuel was expensive. Meanwhile the contribution of hydro-power plants has been consistently decreasing from 40% in 1971 to 14.5% in 2008. Unlike steam turbine and combined cycle power plants, the share of electricity production from the hydro-power plants was always less than its nominal capacity because of drought and limited water resources.

Iran has been very potential for generating electricity from wind and solar sources, but the amount of electricity generated from these resources is still very small. Although since 2001, there were 30% annual growth rate in electricity generation from wind turbines, only less than 0.1% of total electricity generated from this source.

4.4. Emissions production

Based on Tables 6–8, the quantity of all types of fuel consumed in power plants in Iran is illustrated in Fig. 6.

The growth of all types of fuel consumed by Iranian power plants has been depicted in the figure. Natural gas is expected to be the fastest growing component of world energy consumption [24]. This figure shows that natural gas growth is more than other types of fuel in Iranian thermal power plants. The average annual growth of natural gas was 21.9%, fuel oil 8.5% and diesel was 8.8% from 1967 to 2008.

The total of emission in Iranian power plants was calculated based on Eq. (8) and Tables 6–9. For the years between 1967 and 1979 (Table 6), only the total fuel consumed was presented. To estimating the fuel consumption in each type of power plants for these years, the total diesel oil, divided by 27% in diesel engines, 70% in both gas turbine and combined cycle and 3% in steam turbines. Moreover, the total natural gas consumed, divided by 45% in steam turbine and 55% in gas turbines. The total emission in Iranian thermal power plants from 1967 to 2008 presented in Table 13 and illustrated in Fig. 7.

For these 42 years, the average annual growth rate of emissions was 8.6% for CO_2, 8.5% for SO_2, 10.3% for NO_2 and 8.6% for CO. Emission fluctuations in some years are due to the change in the amount and type of fuel used. Fuel use changes might be due to rate of exploitation of hydro-power plants, replacement of natural gas with liquid fuel in some cases and because of over haul and maintenance in some old power plants. As seen in Fig. 7, decreases in CO_2, CO and SO_2 emission were observed due to decrease in the liquid fuel consumption. For instance, in 1998 and 2003, while the liquid fuel specially fuel oil consumption decreased (Fig. 6), CO_2, CO and SO_2 emission also decreased.

Based on Table 1, most of the thermal power plants use both liquid fuel and natural gas. The share of each type of fuel in total

Table 12
Power plants nominal capacity contribution (%) from 1967 to 2008.

Year	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Hydro-power	Wind energy
1967	36.7	9.0	–	21.2	33.1	0
1968	34.8	9.7	–	24.8	30.7	0
1969	33.3	9.7	–	21.8	35.2	0
1970	31.1	9.7	–	22.2	37.0	0
1971	37.4	6.8	–	15.8	40.1	0
1972	35.6	8.2	–	17.8	38.4	0
1973	48.6	8.6	–	14.0	28.8	0
1974	49.4	12.8	–	12.9	25.0	0
1975	45.7	17.7	–	13.3	23.3	0
1976	46.7	17.8	–	13.7	21.8	0
1977	30.9	27.1	–	9.7	32.4	0
1978	24.5	41.1	–	8.7	25.7	0
1979	31.3	37.1	–	8.9	22.8	0
1980	41.4	31.8	–	8.1	18.7	0
1981	43.2	31.0	–	8.1	17.6	0
1982	42.9	31.1	–	8.5	17.5	0
1983	46.2	28.8	–	8.5	16.5	0
1984	47.7	28.6	–	7.9	15.8	0
1985	50.8	26.8	–	7.9	14.6	0
1986	52.7	26.4	–	6.8	14.0	0
1987	53.8	26.2	–	6.3	13.7	0
1988	54.6	25.5	–	5.9	14.0	0
1989	56.0	24.9	–	5.6	13.5	0
1990	54.6	26.6	–	5.6	13.2	0
1991	54.5	26.5	–	5.9	13.2	0
1992	53.4	29.4	–	5.2	12.0	0
1993	52.2	32.6	–	4.5	10.7	0
1994	52.6	34.1	–	3.7	9.6	0
1995	52.7	35.3	–	3.0	8.9	0
1996	51.8	36.4	–	3.0	8.8	0
1997	50.2	38.3	–	2.9	8.6	0
1998	50.7	38.6	–	2.5	8.2	0
1999	52.0	37.8	–	2.3	7.9	0
2000	52.0	24.9	13.8	2.0	7.4	0
2001	51.1	26.1	14.0	1.8	6.9	0
2002	47.1	21.8	20.0	1.6	9.6	0
2003	43.4	22.3	19.9	1.4	12.9	0
2004	40.8	26.0	18.3	1.3	13.4	0.1
2005	38.0	29.4	16.7	1.2	14.7	0.1
2006	34.3	32.8	17.3	0.9	14.5	0.1
2007	31.6	31.2	21.2	0.8	15.0	0.1
2008	29.5	34.1	21	0.8	14.5	0.1

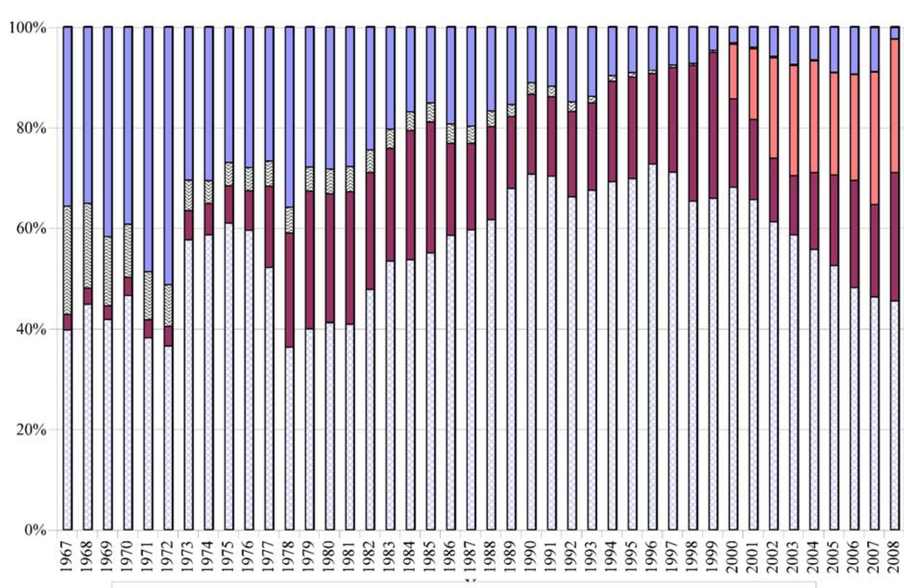


Fig. 4. Pattern of electricity generation for each type of power plants from 1967 to 2008.

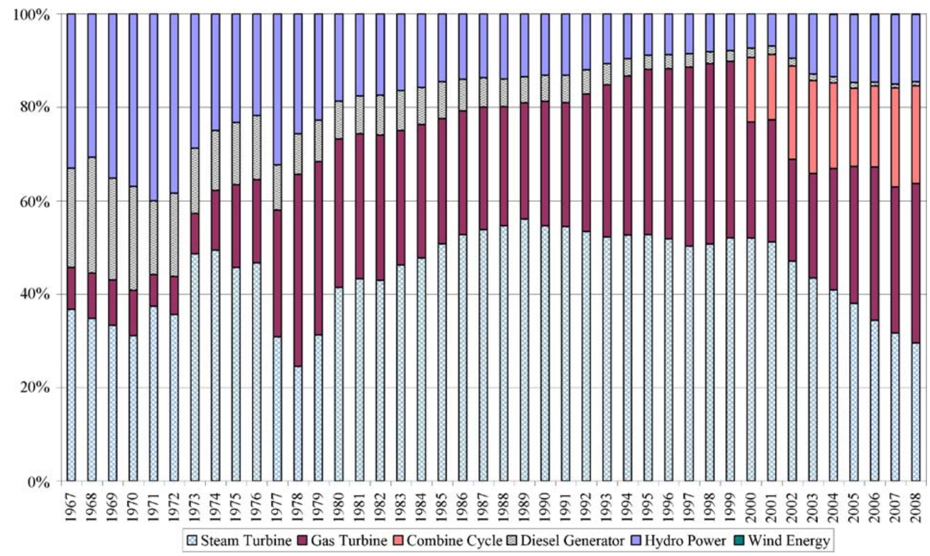


Fig. 5. Pattern of nominal capacity for each type of power plants from 1967 to 2008.

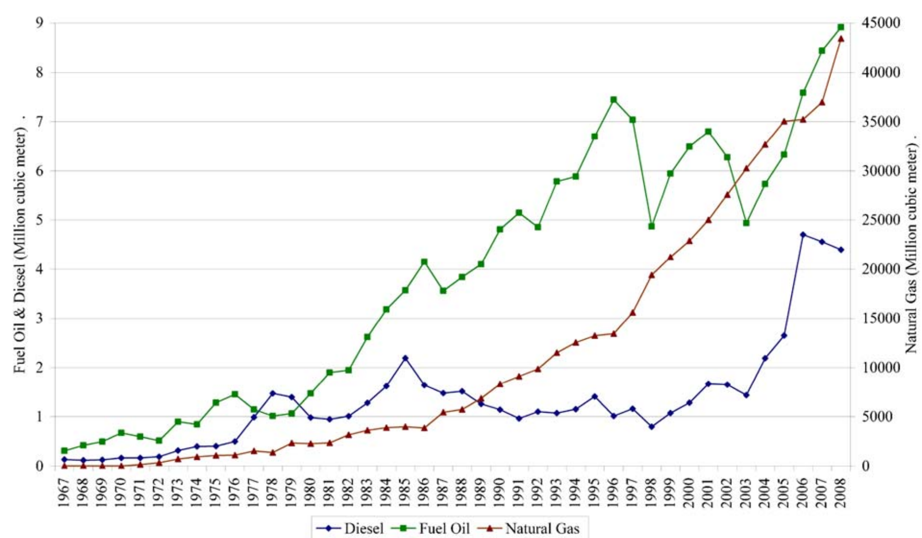


Fig. 6. Total fuel consumed (m^3) in Iranian power plants from 1967 to 2008.

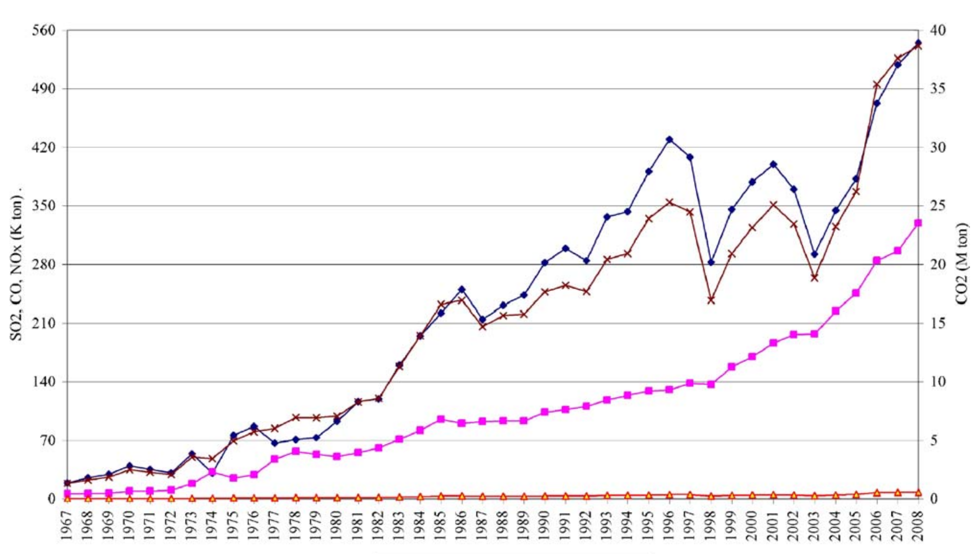


Fig. 7. Total emission (ton) in Iranian power plants from 1967 to 2008.

Table 13
Total emission (ton) in Iranian power plants from 1967 to 2008.

Year	SO_2	NOx	CO	CO_2
1967	18,829	5,890	268	1,302,465
1968	24,811	6,061	323	1,586,613
1969	29,193	6,730	374	1,843,880
1970	39,473	8,835	502	2,476,047
1971	35,252	9,125	458	2,250,943
1972	30,814	10,322	424	2,067,224
1973	53,719	18,060	730	3,566,473
1974	30,481	32,169	747	3,435,522
1975	76,219	24,573	1013	4,965,513
1976	86,762	28,571	1172	5,734,803
1977	66,649	47,308	1281	6,018,168
1978	71,134	56,509	1492	6,952,250
1979	73,201	53,245	1477	6,903,065
1980	92,391	50,410	1473	7,063,199
1981	116,205	55,211	1709	8,274,422
1982	119,405	60,769	1774	8,579,377
1983	159,812	71,240	2339	11,327,089
1984	194,925	81,852	2883	13,938,958
1985	222,008	94,696	3456	16,597,685
1986	249,672	90,327	3475	16,932,701
1987	214,800	92,030	3023	14,719,122
1988	230,951	92,836	3214	15,664,515
1989	243,309	93,024	3216	15,786,170
1990	282,211	103,352	3571	17,639,148
1991	299,450	106,386	3665	18,192,744
1992	284,317	110,351	3573	17,669,607
1993	336,716	118,093	4115	20,425,921
1994	343,172	123,665	4223	20,939,449
1995	390,899	128,805	4830	23,926,777
1996	429,833	130,288	5076	25,317,402
1997	408,194	138,119	4919	24,461,828
1998	282,499	137,085	3400	16,928,487
1999	345,803	157,848	4211	20,923,212
2000	378,614	169,698	4665	23,134,706
2001	399,574	186,279	5079	25,075,893
2002	369,921	196,439	4757	23,451,799
2003	292,472	197,171	3826	18,830,861
2004	344,584	224,405	4755	23,219,729
2005	382,387	245,414	5386	26,225,042
2006	472,695	284,656	7373	35,412,109
2007	519,201	296,129	7795	37,617,064
2008	544,628	329,224	7985	38,658,019

thermal energy consumed and total emission in 2008 calculated by using Eq. (7) and (9) and presented in Table 14.

The year 2008 considered as a sample to show that the most emissions in power plants are due to use liquid fuels. For example although about 18% of thermal energy used in gas turbine power plants is from diesel, more than 95% of SO_2, CO_2 and CO emitted due to consumption of this type of fuel. These results are almost the same for diesel used in combined cycle power plants and for fuel oil used in steam turbine power plants. Therefore, if the use of liquid fuels in thermal power plants can be avoided, the amount of CO_2, SO_2 and CO emitted in these power plants will be decreased significantly.

The emission per unit electricity generation is calculated using Eq. (10) and the results is tabulated in Table 15 and shown in Fig. 8.

The important point observed from this result is the trend of emission per unit electricity generation is decreasing. This due to more natural gas was used instead of liquid fuels and the increasing the thermal power plant efficiency. Increasing the efficiency of thermal power plants was caused by replacing of gas turbine power plants with combined cycle and by increasing the efficiency of new turbines.

In recent 9 years (2000–2008), there was detail information of fuel consumed and electricity generated for all types of power plants. Therefore, the amount of total emission and emission per unit of electricity generation in each type of power plants were calculated more precisely. These data calculated by using Eqs. (8) and (11) and tabulated in Tables 16 and 17.

The emission per unit electricity generation for each type of power plants in Iran was calculated by using Eq. (12) based on the data in Table 17 and the result is tabulated in Table 18.

Table 14
Fuel types contribution (%) in total emission and total energy consumed in power plants in 2008.

Fuel type	Pollutant	Steam turbine		Gas turbine		Combined cycle	
		Emission	Energy	Emission	Energy	Emission	Energy
Natural gas	SO_2	0.03	61.5	4.72	81.9	7.61	88.2
	CO_2	0.11		0.36		0.59	
	NO_x	59.21		62.88		73.81	
	CO	0.00		0.00		0.00	
Diesel	SO_2	0.01	0.2	95.29	18.1	92.43	11.8
	CO_2	0.44		99.64		99.41	
	NO_x	0.20		37.12		26.19	
	CO	0.50		99.99		99.99	
Fuel oil	SO_2	99.96	38.3	–	–	–	–
	CO_2	99.45		–		–	
	NO_x	40.59		–		–	
	CO	99.50		–		–	

Table 15
Emission per unit of electricity generation (kg/GWh) from 1967 to 2008.

Year	SO_2	NOx	CO	CO_2
1967	10,222	3198	146	707,093
1968	10,206	2493	133	652,659
1969	9,131	2105	117	576,753
1970	9,275	2076	118	581,778
1971	6,421	1662	83	410,008
1972	4,485	1503	62	300,906
1973	5,761	1937	78	382,505
1974	2,730	2881	67	307,705
1975	5,965	1923	79	388,599
1976	6,105	2011	82	403,547
1977	4,230	3003	81	381,985
1978	4,091	3250	86	399,876
1979	3,765	2739	76	355,078
1980	4,647	2536	74	355,274
1981	5,186	2464	76	369,295
1982	4,536	2309	67	325,927
1983	5,238	2335	77	371,270
1984	5,717	2401	85	408,839
1985	6,046	2579	94	452,007
1986	6,394	2313	89	433,671
1987	5,048	2163	71	345,893
1988	5,276	2121	73	357,842
1989	4,994	1909	66	323,985
1990	5,141	1883	65	321,319
1991	5,015	1782	61	304,685
1992	4,444	1725	56	276,165
1993	4,720	1655	58	286,338
1994	4,452	1604	55	271,638
1995	4,884	1609	60	298,920
1996	5,008	1518	59	294,989
1997	4,422	1496	53	264,997
1998	2,887	1401	35	172,983
1999	3,226	1472	39	195,166
2000	3,197	1433	39	195,327
2001	3,142	1465	40	197,186
2002	2,684	1425	35	170,170
2003	1,954	1317	26	125,811
2004	2,116	1378	29	142,565
2005	2,147	1378	30	147,272
2006	2,455	1478	38	183,918
2007	2,545	1452	38	184,415
2008	2,542	1536	37	180,409

Table 16
Total emission (ton) in thermal power plants from 2000 to 2008.

Year	Emission	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
2000	SO_2	366,917	6,860	3,826	1,011	378,614
	CO_2	19,890,113	1,901,703	1,056,993	285,897	23,134,706
	NO_x	98,014	25,092	38,814	7,778	169,698
	CO	3,924	436	240	64	4,665
2001	SO_2	384,544	10,617	3,476	937	399,574
	CO_2	20,907,405	2,941,641	961,911	264,936	25,075,893
	NO_x	106,277	48,971	23,822	7,208	186,279
	CO	4,127	673	220	60	5,079
2002	SO_2	354,965	10,757	3,178	1,021	369,921
	CO_2	19,304,603	2,981,089	877,231	288,876	23,451,799
	NO_x	107,210	44,422	36,947	7,859	196,439
	CO	3,810	683	199	65	4,757
2003	SO_2	279,234	8,969	3,461	808	292,472
	CO_2	15,162,117	2,484,901	955,349	228,494	18,830,861
	NO_x	108,317	42,260	40,376	6,217	197,171
	CO	2,989	569	217	52	3,826
2004	SO_2	324,299	13,765	5,787	734	344,584
	CO_2	17,597,264	3,814,314	1,600,671	207,480	23,219,729
	NO_x	113,879	59,141	45,741	5,645	224,405
	CO	3,470	874	365	47	4,755
2005	SO_2	357,924	17,603	6,277	583	382,387
	CO_2	19,445,619	4,878,072	1,736,432	164,920	26,225,042
	NO_x	118,282	76,034	46,611	4,487	245,414
	CO	3,836	1,117	396	37	5,386
2006	SO_2	429,140	31,556	11,389	611	472,695
	CO_2	23,335,635	8,748,899	3,154,675	172,900	35,412,109
	NO_x	117,418	105,256	57,278	4,704	284,656
	CO	4,606	2,006	722	39	7,373
2007	SO_2	477,384	21,459	19,737	621	519,201
	CO_2	26,024,555	5,947,345	5,469,604	175,560	37,617,064
	NO_x	120,746	86,793	83,813	4,776	296,129
	CO	5,140	1,363	1,253	40	7,795
2008	SO_2	503,667	28,080	12,326	555	544,628
	CO_2	27,307,881	7,781,003	3,412,195	156,940	38,658,019
	NO_x	125,894	121,789	77,271	4,270	329,224
	CO	5,389	1,782	779	35	7,985

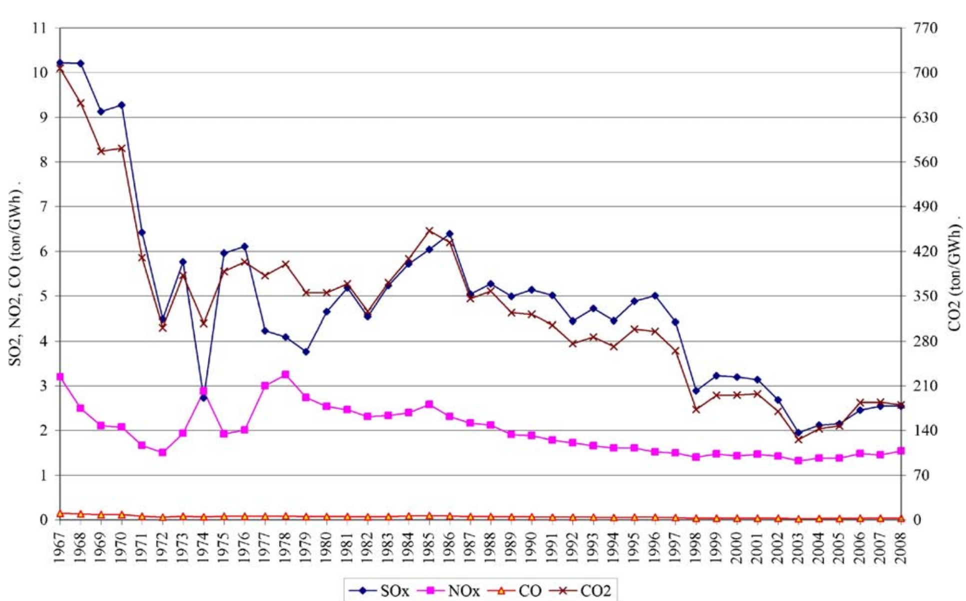


Fig. 8. Emission per unit electricity generation (ton/GWh) from 1967 to 2008.

Table 17
Emission per unit electricity generation (kg/GWh) in thermal power plants from 2000 to 2008.

Year	Emission	Steam turbine	Gas turbine	Combined cycle	Diesel engine
2000	SO_2	4,546	329	298	2,800
	CO_2	246,439	91,143	82,224	791,958
	NO_x	1,214	1,203	3,019	21,547
	CO	49	21	19	179
2001	SO_2	4,605	522	194	2,856
	CO_2	250,358	144,595	53,741	807,732
	NO_x	1,273	2,407	1,331	21,976
	CO	49	33	12	182
2002	SO_2	4,213	614	115	2,869
	CO_2	229,108	170,047	31,800	811,449
	NO_x	1,272	2,534	1,339	22,077
	CO	45	39	7	183
2003	SO_2	3,185	507	105	2,786
	CO_2	172,945	140,414	29,042	787,910
	NO_x	1,236	2,388	1,227	21,436
	CO	34	32	7	178
2004	SO_2	3,575	551	160	2,911
	CO_2	193,982	152,701	44,156	823,333
	NO_x	1,255	2,368	1,262	22,400
	CO	38	35	10	186
2005	SO_2	3,833	548	173	2,751
	CO_2	208,235	151,828	47,976	777,925
	NO_x	1,267	2,367	1,288	21,165
	CO	41	35	11	175
2006	SO_2	4,640	765	282	2,779
	CO_2	252,329	212,172	78,196	785,909
	NO_x	1,270	2,553	1,420	21,382
	CO	50	49	18	177
2007	SO_2	5,066	571	367	2,759
	CO_2	276,187	158,157	101,673	780,267
	NO_x	1,281	2,308	1,558	21,229
	CO	55	36	23	176
2008	SO_2	5,182	511	216	2,720
	CO_2	280,942	141,702	59,847	769,314
	NO_x	1,295	2,218	1,355	20,931
	CO	55	32	14	174

Table 18
Emission per unit electricity generation (kg/GWh) in thermal power plants.

Emission	Steam turbine	Gas turbine	Combined cycle	Diesel engine
SO_2	4,316	546	212	2,803
CO_2	234,503	151,418	58,740	792,866
NO_x	1,263	2,260	1,533	21,571
CO	46	35	13	179

The data of this table has been calculated by using the past 9-year fuel mix. Therefore, by changing the fuel mix used in thermal power plants, this data will be changed. For example, by increasing the contribution of natural gas in power plants, the emission per unit electricity generation will be decreased.

The data for year 2008 in Table 16 is selected to show the share of each type of power plant for total emission. The contribution of each type of thermal power plants in total emission in 2008 is presented in Fig. 9.

The figure shows that the contribution of diesel engines for all types of emission was insignificant. Fig. 10 shows the comparison of each type of emission in all thermal power plants in Iran except the diesel engine that eliminated due to insignificancy share in total emission.

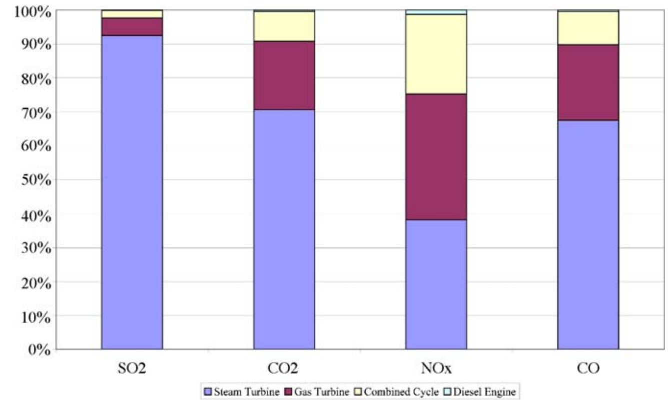


Fig. 9. Power plants emission contribution in 2008.

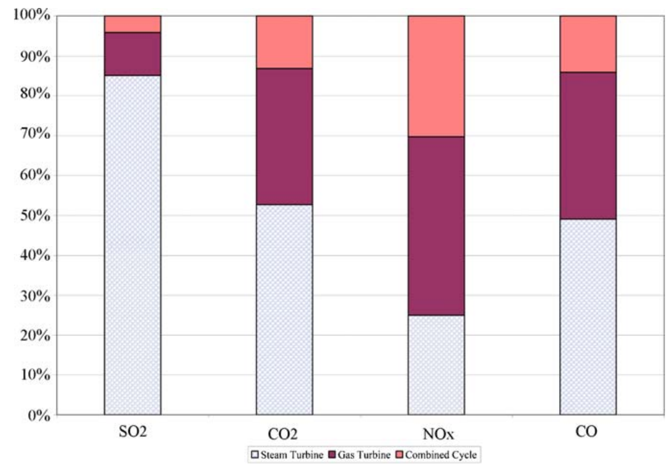


Fig. 10. Comparison between thermal power plants with regard to emission.

Comparison the thermal power plants with regard to emission shows that, the worst type is steam turbine that produces the highest amount of emission while the best type is the combined cycle. Except for NO_x emission, that the gas turbine power plant has higher emission.

5. Conclusions

This study describes the pattern of electricity generation and emission in Iran in the past 42 years since 1967–2008. It shows thermal power generators that using fossil fuels plays an important role in the Iranian electricity generation and these are also an important source of emissions in the country. The data shows that the best type of thermal power plants with regard to air pollution is combined cycle, gas turbine and steam turbine, respectively. The data has been calculated based on the past fuel mix used in the power plants. Therefore, by alteration the fuel mix, will give a different scenario of emission generated. For example, by replacing liquid fuel types with natural gas, the amount of emissions per unit of electricity generation will decrease significantly.

Economical growth in Iran depends on electricity consumption. The increase in electricity consumption is expected to be in upcoming years around 10% based country's economic growth. The hydro-power plants are the cleanest energy source, since it has no emission. However, the study shows that these plants were unstable and can be used only as supplementary because of unreliability of water resources. Iran has many potential for generating electricity from non-hydro renewable energy resources

such as wind and solar. The development of these resources provides more diverse energy resources besides the dominant fossil fuels. In addition, it helps to meet the growing energy demand and addressing environmental concerns and sustainability issues, but the amount of electricity generated from these resources were still under 0.1%. Therefore, based on data analyses Iran has to cover required new capacities by launching thermal power plants. Using more thermal power plants will cause increasing emission in the future. On the positive side, it is possible to achieve significant emission reductions with gradual conversion of liquid fuel to natural gas and increasing the contribution of the combined cycle as a more efficient type of thermal power plants.

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